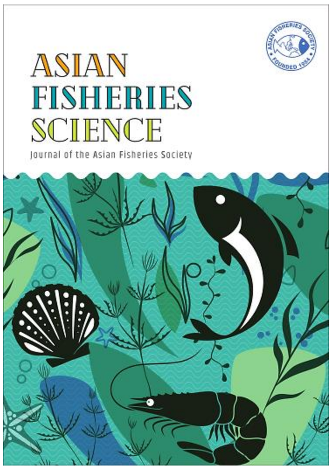

Shrimp Yield in Relation to the Ecological Parameters of an Organic Shrimp Model in the Mekong Delta of Vietnam: A Case Study

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Abstract

This study was carried out to observe the shrimp yield and ecological parameters of the organic shrimp model certified by Naturland at the coastal Tam Giang commune, Camau province, Mekong delta of Vietnam. The sampling of pond water and sediment and the collection of shrimp yield data were conducted in 2015. The results showed that the ponds were shallow (68.81 ± 3.40 cm) but the water and sediment were in general suitable for shrimp culture except in some cases when iron and oxygen levels were high. The total shrimp yield was low (355.4 $kg.ha^{-1}.year^{-1}$) and the wild shrimp, *Penaeus indicus* H. Milne Edwards, 1837, *Penaeus merguiensis* de Man, 1888 [in de Man, 1887-1888], *Metapenaeus ensis* (De Haan, 1844 [in De Haan, 1833-1850]) and *Metapenaeus lysianassa* (de Man, 1888 [in de Man, 1887-1888]) cultured together with *Penaeus monodon* Fabricius, 1798, contributed significantly (55 %) to the total yield. Positive correlations between the total yield with pH_{H2O} ($P < 0.05$) and pH_{KCl} ($P < 0.001$) suggested that shrimp grew well in neutral or near-neutral pond bottom. Yield of wild shrimp and the total yield were positively correlated with the water depth (both at $P < 0.05$). To improve pond conditions, it is recommended that the water depth be increased to about 80–90 cm, to avoid disturbance to the mangrove soil. In addition, the water level should be higher than the forest floor, and lime (CaO) should be applied to the pond sediment that is deposited on the dikes after harvest.

Keywords: mangrove, Naturland, organic shrimp, shrimp yield, Vietnam

Introduction

In the context of increasing demand for cleaner food production worldwide, organic shrimp model has been developed in the coastal areas of many countries in the tropics, such as Thailand, Bangladesh, Indonesia, India, Madagascar, and Vietnam (Paul and Vogl, 2012; Willer et al., 2014; iPFES, 2015). There are several organizations such as Ecocert (France), IMO (Switzerland), National Programme for Organic Production (India), and Japanese Agricultural Organic Standard (Japan) that have examined and certified organic shrimp products. According to Naturland's standards (by IMO), shrimps of this model are cultured in the near-natural environment, preferably in polyculture systems, without using antibiotics and chemicals, and with special emphasis on protection of mangrove forests and mangrove ecosystems (Naturland, 2019). The near-natural environment polyculture system is expected to produce clean shrimp products while preserving the coastal environment. With the rising health and environmental awareness of global consumers, the organic shrimp model is expected to grow faster in the future (Mukul et al., 2013; https://aindustryreports.com).

In Vietnam, the organic shrimp model was introduced in 1999 and first certified by Naturland in 2001 in the coastal part of the Mekong delta where shrimp aquaculture had a very long history and played a key role in supporting the coastal communities. This model was developed based on the background of the mixed shrimp-mangrove systems established in the 1980s in the area (Camimex, 2012). In this model, black tiger shrimp (*Penaeus monodon* Fabricius, 1798) are cultured at low densities in the mangrove forests, and often cultured with marine crab (*Scylla serrata* Forskal, 1775), blood cockle (*Anadara granosa* Linnaeus, 1758), and wild shrimps, *Penaeus indicus* H. Milne Edwards, 1837, *Penaeus merguiensis* de Man, 1888 [in de Man, 1887-1888], *Metapenaeus ensis* (De Haan, 1844 [in De Haan, 1833-1850]) and *Metapenaeus lysianassa* (de Man, 1888 [in de Man, 1887-1888]) (Jonell and Henriksson, 2015). Shrimps are raised in the long channels alternately mixed with bands of mangrove forests. The black tiger shrimps from this model are of high quality, meeting three current international organic standards (EU organic regulations, Naturland standard, and Bio Suisse standard), and being accepted in Swiss and EU markets (Camimex, 2012).

Before mangrove areas are accepted as sites for organic shrimp model development, environmental factors highly toxic to human, such as heavy metals, dioxins, pesticides, prohibited antibiotics, and toxicity are thoroughly examined (Xuyen, 2011). However, due to the poor coverage of the organic shrimp model as compared to the whole area of shrimp-mangrove system in general, the physico-chemical characteristics of pond water and sediment closely related to shrimp growth and yield in this model have received little attention. Currently there is little information on the quality of the organic shrimp model (Sinh and Chanh, 2009; Mai et al., 2010; Tho et al., 2017). Thus, the present study investigates the shrimp yield and ecological parameters of the organic shrimp model in a coastal commune in the Mekong delta of Vietnam.

Materials and Methods

Study area

The coastal Tam Giang commune in Nam Can district, Camau Province, Mekong delta of Vietnam where the organic shrimp model occupies more than 4,000 ha in 2014 was selected as the study area. It is connected to both the East Sea and the West Sea through a dense network of rivers and canals. The tidal regime of the area is quite complex as it is simultaneously influenced by both the semi-diurnal tidal regime from the East Sea and diurnal tidal regime from the West Sea. The area is subjected to a high rainfall rate of 2,360 mm.year^{-1}, mostly in the wet season (90 %), and an averaged evaporation of 1,022 mm.year^{-1} (http://www.camau.gov.vn). Shrimp ponds and mangroves, either isolated or combined, are the major land use types in the area.

The organic shrimp model

In the 1980s, long channels were mechanically dug in parallel bands within the mangrove areas (Fig. 1) for the culture of black tiger shrimp (*P. monodon*) in mixed shrimp-mangrove systems in Camau province. In 1999, some of the ponds following this model were converted to the organic shrimp ponds certified by Naturland - one of the world's leading international associations for organic agriculture. As a result of the development history, the organic shrimp ponds which ranged from 4-5 ha.pond^{-1} were miscellaneously distributed with the mixed shrimp-mangrove ponds. Mangrove trees in the organic shrimp model are pure stands of replanted Rhizophora (*Rhizophora apiculata* Blume) with an averaged density of 10,000 trees.ha^{-1}. The forest ratio must be maintained to at least 50 % of the whole pond area (Camimex, 2012). The exploitation of mangrove forests can be performed only with permission from the forestry authority.

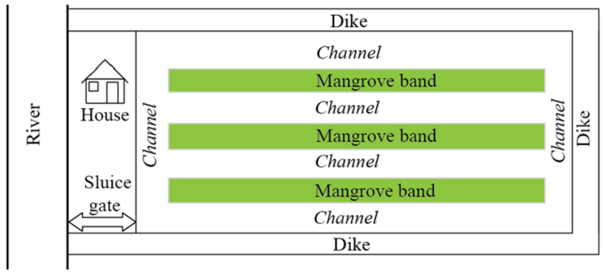

Fig. 1. The layout of an organic shrimp pond used for this research in Camau province, Mekong delta, Vietnam.

A new grow-out cycle starts in September and ends in July the year after. Water of the grow-out ponds is taken directly from the rivers at high tides without any treatment. During water intake, farmers use a net (1 × 1 cm) to prevent undesired objects and aggressive fish from entering the ponds. All of the 15-day shrimp postlarvae are screened for subclinical levels of pathogens (FAO, 2007) before stocking. The stocking density at the start of the grow-out cycle was about 3-5 postlarvae.m^{-2} and about 50 % more shrimp larvae were introduced in the following months until February-March. The farmers also release marine crabs (*Scylla serrata* Forskal, 1775) to the ponds at a stocking density of 0.1-0.2 individual.m^{-2} after every 3 months. There is no regular water exchange except at harvests. All shrimps (cultured and wild) rely entirely on natural food, provided either by materials from the input water or by mangrove detritus within the ponds. No chemicals are allowed in the model. Four to five months after stocking, farmers harvest market-sized shrimps by draining out part of the pond water twice a month (at the end/start and the middle of the lunar months, over 3-4 days.period^{-1}). The cultured black tiger shrimp is exported while the wild shrimps are sold in the local market. As a result of continuous stocking and partial-harvesting method, shrimps of different ages and sizes are present in the model at a certain point of time during the grow-out cycle. In August, accumulated sediment in the channel is dredged and deposited on the dykes. Quicklime (CaO) is then used to disinfect the pond bottom.

Sampling and sample analysis

Pond water

Sampling of water was conducted from eight ponds, three times in March during the middle of the dry season, and in July at the start of the wet season, and in November 2015 during the transition between wet and dry season (Fig. 2). Samples were collected in the channel located in the middle of the ponds. Dissolved oxygen (DO), pH, temperature, turbidity and salinity were measured at 20-cm depth in the channel at three different locations (at both ends and in the middle) using the multiparameter water quality meter (WQC-22A, TOA-DKK, Japan), followed by water sampling. Water depths were measured in the channel using a ruler (3 measurements/location). Water samples for hydrogen sulphide (H_2S) analysis were collected near the channel bottom. There were 72 water samples collected (8 ponds × 3 locations/pond × 3 times). All samples were stored in a dark box at 4 °C and transported the same day to the laboratory for analysis. The parameters analysed and methods used were as follows: (1) total suspended solids (TSS): gravimetric method, 105 °C, (2) NO_2-N: diazo method, (3) NO_3-N: EPA 352.1 method, (4) PO_4-P: ascorbic acid method, (5) Fe^{2+} and Fe^{3+}: phenanthroline method, (6) NH_4-N: SMEWW 4500-NH_3-F method, (7) H_2S: Iodometric method (Rodier, 1984), (8) chlorophyll-*a* (Chl-*a*): spectrophotometer method, (9) alkalinity: titration method, methyl orange 0.1 % indicator, and (10) total hardness: EDTA titrimetric method (APHA, 1999).

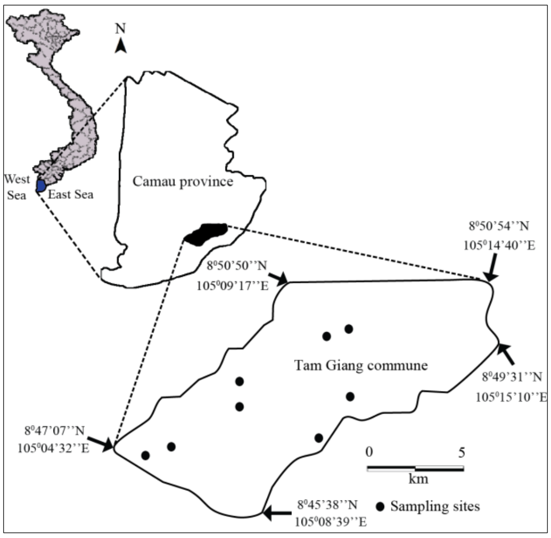

Fig. 2. Organic shrimp model study area with the sampling sites in a coastal commune in the Mekong delta of Vietnam.

Pond sediment

Pond sediment was collected in the channel (0–20 cm depth) using a Petersen grab at the same place and time as water sampling. The redox potential (E_h) and pH of fresh sediment (pH_w) were measured *in-situ* using a pH-meter (pH 62K) with a glass electrode for pH_w and an EMC130 Meinsberg electrode for E_h. There were 72 sediment samples (8 ponds × 3 locations/pond × 3 times). The samples were stored in a dark box and transported the same day to the laboratory where they were air-dried (except the analysis of iron), passed through a 2-mm sieve, and analysed. The parameters and methods were as follows: pH_{H2O} and pH_{KCl} (pH 62K, 1/2.5, w/v), exchange acidity (extracted with KCl 1N, titrated by NaOH standard solution), Fe^{2+} and Fe^{3+} (1,10-phenanthroline method), organic matter (OM) (Walkley-Black method), and total N (Kjeldahl method) (Rowell, 1994; van Reeuwijk, 2002). The particle size of pond sediment were determined by the ASTM D422 method with 3 levels: (1) 0.063–2.0 mm (sand), (2) 0.002–0.063 mm (silt), and <0.002 mm (clay) (ASTM D422-63, 2007).

Shrimp yield

Data on shrimp yield of cultured and wild shrimps from the ponds were collected twice a month during shrimp harvests at 87.5 % of the ponds in the sampling period. Shrimp were harvested nine times from 3 March 2015 to 2 July 2015 and thereafter no shrimp were harvested until the end of the year

Statistical analysis

Variations of physico-chemical characteristics of pond water and sediment between sampling times were determined using repeated-measures ANOVA. Parameters that did not follow the normal distributions (by Shapiro-Wilk test), or satisfy the Sphericity assumption (by Mauchly's test of Sphericity) were analysed by Friedman ANOVA test, followed by Wilcoxon matched pairs test (with Bonferoni adjusted P = 0.05/3 = 0.017). Shrimp yield (log-transformed) from 2–5 April 2015 and 29 June–2 July 2015 were respectively regarded as being corresponding to the physico-chemical data of March and July 2015. Correlations among the parameters were tested using a Pearson correlation matrix. The 95 % confidence intervals of all parameters were demonstrated as mean ± 1.96 × standard error. All the statistical tests were performed using SPSS 16.0 and Statistica 7.0 software packages.

Results

The average depth of the organic shrimp ponds was 68.81 ± 3.40 cm and did not differ between the sampling periods. The pond water was alkaline (pH 7.59 ± 0.07) and temperature ranged from 26.3–32.4 °C. Turbidity and TSS were 24.06 ± 2.37 NTU and 12.49 ± 1.48 $mg.L^{-1}$, respectively. Averaged DO concentrations were 6.93 ± 0.27 $mg.L^{-1}$. The average iron contents were 0.08 ± 0.01 $mg.L^{-1}$ and 0.64 ± 0.14 $mg.L^{-1}$, respectively for Fe^{2+} and Fe^{3+}. Concentrations of Chl-*a* did not exceed 0.06 $\mu g.L^{-1}$. The nutritional elements, NO_2-N, NO_3-N, NH_4-N, and PO_4-P were 0.01 ± 0.00, 0.06 ± 0.02, 0.21 ± 0.05, and 0.02 ± 0.01 $mg.L^{-1}$ respectively (Table 1). The H_2S levels on pond bottom were not more than 0.04 $mg.L^{-1}$.

Table 1. Descriptive statistics of the physico-chemical characteristics of pond water in the organic shrimp model of this study.

Parameter	Unit	Mean ± 1.96 × SE	Minimum	Maximum
Depth	cm	68.81 ± 3.40	38.00	104.00
pH	-	7.59 ± 0.07	7.01	8.82
DO	$mg.L^{-1}$	6.93 ± 0.27	3.90	8.70
Temperature	°C	29.57 ± 0.36	26.30	32.40
Salinity	$g.L^{-1}$	27.06 ± 1.27	18.90	34.30
Turbidity	NTU	24.06 ± 2.37	8.70	55.99
Alkalinity	$mg.L^{-1}$	100.42 ± 5.42	72.00	189.00
Total hardness	$mg.L^{-1}$	4,622.15 ± 226.27	3,127.10	5,836.00
TSS	$mg.L^{-1}$	12.49 ± 1.48	2.00	23.50
NO_2-N	$mg.L^{-1}$	0.01 ± 0.00	0.002	0.02
NO_3-N	$mg.L^{-1}$	0.06 ± 0.02	0.02	0.69
NH_4-N	$mg.L^{-1}$	0.21 ± 0.05	0.02	1.18
PO_4-P	$mg.L^{-1}$	0.02 ± 0.01	0.001	0.20
Fe^{2+}	$mg.L^{-1}$	0.08 ± 0.01	0.01	0.25
Fe^{3+}	$mg.L^{-1}$	0.64 ± 0.14	0.07	3.22

Pond sediment ranged from slightly acidic to slightly alkaline (pH_w 6.05–7.64, pH_{H20} 6.63 - 7.78, pH_{KCl} 6.35–7.43). The exchange acidity ranged from 0.03–0.12 $meq.100g^{-1}$. The sediment was anaerobic (E_h -299 – -1 mV, -177.8 ± 14.75 mV on average). The Fe^{2+}/Fe^{3+} ratio was 9.89 ± 3.35. The OM and total N contents were respectively 4.20 ± 0.33 % and 0.30 ± 0.02 %. The average soil organic carbon ranged from 1.40–5.41 % (2.44 ± 0.10 %).

The C/N ratio varied largely from 3.90 to 12.16. Organic matter showed negative correlations with both pH_{H20} and pH_{KCl} ($r = -0.47^{***}$) but a positive correlation with exchange acidity ($r = 0.31^{**}$). Silt and clay content were dominant in the sediment, and at the start of the wet season, the silt content increased while clay content decreased (Fig. 3)

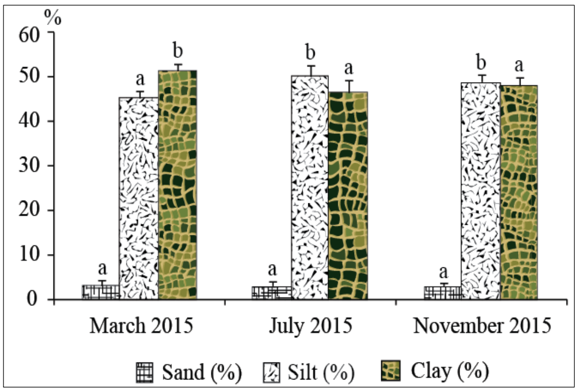

Fig. 3. Variations of particle size in pond sediment. For each of the sizes, mean values with the same superscript are not statistically different between sampling times.

Averaged shrimp yields were 160.7 and 194.8 $kg.ha^{-1}.year^{-1}$ for cultured and wild shrimp respectively. The total shrimp yield was 355.4 $kg.ha^{-1}.year^{-1}$. The yield of cultured shrimp was inversely correlated with Fe^{2+} but positively correlated with pH_{KCl} of pond sediment. The yield of wild shrimp and total yield were positively correlated with water depth, temperature, pH_{H20} and pH_{KCl} of pond sediment. Besides, wild shrimp yield was positively correlated with turbidity while the total yield was inversely correlated with Fe^{2+} content (Table 2).

Table 2. Correlations between shrimp yields (log-transformed) and the physico-chemical characteristics of pond water and sediment in the organic shrimp model of this study. Significance levels: ns (not significant), * ($P < 0.05$), ** ($P < 0.01$), and *** ($P < 0.001$).

Parameters	Yield of cultured shrimp	Yield of wild shrimp	Total yield
Water characteristics			
Water depth (cm)	ns	0.37*	0.37*
Temperature (°C)	ns	0.41*	0.39*
Turbidity (NTU)	ns	0.38*	ns
Fe^{2+} ($mg.L^{-1}$)	-0.38*	ns	-0.40*
Sediment characteristics			
pH_{H20}	ns	0.46*	0.45*
pH_{KCl}	0.44*	0.55**	0.59***

Discussion

Characteristics of pond water

The current water depth of the ponds (68.81 ± 3.40 cm) was higher than that of the mixed shrimp-mangrove systems in the past (50.5 cm on average) (Johnston et al., 2000) but much lower than that (110–120 cm) of the shrimp-mangrove system currently practiced in the neighbouring Ngoc Hien district, Camau province (Toan, 2011). These differences are probably due to the differences in the topography and experience of the local farmers. The organic shrimp farmers in the study area try to maintain a stable water level in their ponds, and thus the water depth remained unchanged during the sampling period. The water depth of the organic shrimp ponds in this research was shallow when compared to the recommended water level for commercial aquaculture ponds which is 1–1.2 m at the shallow end and 1.5–1.8 m at the outlet (Egna and Boyd, 1997).

Pond temperature (29.6 ± 0.36 °C) was associated with the seasonal temperature changes and the mangrove forest. It was lower than those recorded in the rice field-based extensive shrimp system (30.6 °C, 32.7 °C on average) in Camau province, Mekong delta of Vietnam (Tho et al., 2006; Tho et al., 2011). In general, the result was consistent with the finding of Le (2006) that the water temperature of shrimp-mangrove systems is reduced as a result of the shading provided by the mangrove trees. The concentrations of Chl-*a* and nutritional elements (N, P) were very low, being consistent with the low turbidity and TSS in the water column (Table 1). The low concentrations of Chl-*a* and nutritional elements (N, P) were most probably due to the effects of water exchange during harvests and annual sediment dredging which substantially remove the organic deposited at the pond bottom. In this model, materials from the input water and the decomposition of organic matter from mangrove detritus provided nutrients for aquatic species, including shrimps. Most of the physico-chemical characteristics of pond water were within the acceptable range for shrimp growth (Table 3). The H_2S concentrations on the pond bottom (≤ 0.04 mg.L^{-1}) were also within the accepted levels as recommended in several standards (Lazur, 2007; Vietnamese Standard 02-19:2014).

Although pond water was alkaline (Table 1), the risk of acidification has existed due to the presence of pyritic materials in the mangrove soils of the model (Tho et al., 2017). The acidification was due to the production and release of acidic components (Al, Fe) from the oxidised pyritic materials on the dykes to pond water during heavy rains. Oxidation of pond bottom during and after sediment dredging also provided acidic components to pond water. The significant pH reduction and an associated increase in Fe contents in the pond water from March to July possess a threat to the shrimp. Iron content exceeded the limits during all sampling periods (Table 3).

Table 3. Comparisons between the physico-chemical characteristics of pond water in the organic shrimp model of this study and limits for shrimp growth. In each of the rows, mean values with the same superscript are not statistically different at P < 0.05.

Parameter	Unit	March 2015	July 2015	November 2015	SE	Limit
Depth	cm	70.58^a	63.88^a	71.96^a	1.736	-
pH	-	7.68^b	7.40^a	7.70^b	0.037	7-9 (Haws and Boyd, 2001) 7-8.5 (Lazur, 2007)
DO	mg.L^{-1}	6.74^a	7.52^b	7.08^{ab}	0.137	> 4 (Lazur, 2007) ≥ 3.5 (Vietnamese Standard 02-19:2014)
Temperature	°C	30.16^b	27.75^a	30.79^c	0.182	26-30 (Lazur, 2007)
Salinity	g.L^{-1}	33.52^c	27.27^b	20.40^a	0.650	5-35 (Haws and Boyd, 2001)
Turbidity	NTU	26.30^a	24.89^a	20.99^a	1.211	-
Alkalinity	mg.L^{-1}	122.92^c	94.45^b	83.90^a	2.767	60-180 (Vietnamese Standard 02-19:2014)
Total hardness	mg.L^{-1}	5,732.5^c	4,735.9^b	3,398.1^a	115.444	-
TSS	mg.L^{-1}	19.92^c	5.92^a	11.62^b	0.757	50 (Vietnamese Standard 10-MT:2015)
NO_2-N	mg.L^{-1}	0.004^a	0.011^b	0.003^a	0.001	< 0.08 (Jayasinghe et al., 1994) < 0.07 (Haws and Boyd, 2001)
NO_3-N	mg.L^{-1}	0.05^b	0.11^c	0.02^a	0.010	0.05-2.26 (Haws and Boyd, 2001)
NH_4-N	mg.L^{-1}	0.07^a	0.44^c	0.11^b	0.027	0.16-1.56 (Haws and Boyd, 2001)
PO_4-P	mg.L^{-1}	0.034^b	0.013^a	0.023^a	0.005	-
Fe^{2+}	mg.L^{-1}	0.04^a	0.11^b	0.09^b	0.006	0 (Haws and Boyd, 2001)
Fe^{3+}	mg.L^{-1}	0.37^a	0.95^b	0.61^{ab}	0.069	Trace (Haws and Boyd, 2001)

The high dissolved oxygen concentrations of 8.7 mg.L^{-1} exceeded the saturation level (6.59 mg.L^{-1} at 30 °C and 25 g.L^{-1} salinity (USGS, 2011)), most probably due to an excessive increase in photosynthesis rate at high temperature during daytime. Because photosynthesis removes carbon dioxide (Boyd and Tucker, 1998; Tho et al., 2011), and excessive photosynthesis also results in a higher pH, as seen by a positive correlation between pH and DO (R = 0.35, P < 0.01). This phenomenon is often associated with the lack of oxygen in the water column from midnight to the next morning due to the imbalance between photosynthesis (does not occur) and respiration processes (occur normally) (Lazur, 2007; Tho et al., 2011; Sombatjinda et al., 2014). Excessive DO levels may harm shrimps if it occurs at all depths in the shrimp ponds (Boyd and Fast, 1992; Boyd, 1998).

Characteristics of pond sediment

The sediment of the organic shrimp ponds ranged from slightly acidic to slightly alkaline, as shown by the pH values. The negative E_h (-177.8 ± 14.75 mV) and the Fe^{2+}/Fe^{3+} ratio (9.89 ± 3.35) indicated a reduced bottom environment. Based on a review by Avnimelech and Ritvo (2003), it can be inferred that sulphate reduction and methanogenesis were the two processes dominant in the sediment of the organic shrimp ponds.

Soil organic carbon contents at 2.44 ± 0.10 % were slightly higher as compared to the optimal range in shrimp aquaculture ponds reported as 1.5– 2.5 % (Boyd, 2003). A large variation of the C/N ratio (3.90–12.16) indicated a high diversity of organic matter origins and stages of organic matter decomposition at the pond bottom. This ratio in the organic shrimp model was low as compared to that of Gazi bay in Kenya (25.3 ± 1.3) (Middelburg et al., 1996), Ubatuba bay in Brasil (6.67–16.56) (Burone et al., 2003), or Xuan Thuy National Park (Vietnam) (4.5–19.5) (Tue et al., 2012). The relatively low C/N ratio indicated a high rate of organic matter decomposition in the sediment of the organic shrimp model. The negative correlations between OM and pH_{H2O} and pH_{KCl} (both at r = -0.47***) and positive correlation between OM and exchange acidity (r = 0.31**) suggested that weak organic acids were released to pond sediment as OM was decomposed. This process occurs as a result of aerobic respiration in the top layer of the sediment (0–2 mm), or due to sulphate reduction under anaerobic conditions of the reduced layer beneath the sediment surface (>2 mm) (Matsui et al., 2015).

Silt and clay contents were dominant (Fig. 3), most probably because the particle sizes of pond sediment were largely dependent on the TSS content of the input water. The sand content was about 3 % and remained almost constant between the sampling periods. Because of the high clay content in pond sediment, turbidity remained high in the water column for a long time after water exchange or any actions that cause sediment disturbances. The high turbidity in pond water was because it takes a long time for the fine-sized sediment particles to settle down to pond bottom. According to Stoke's law, the settling rate of a clay mineral of 0.001 mm diameter at 30 °C is 1.03×10^{-6} $m.s^{-1}$, which means that a period of more than 11 days is required for it to settle down to a pond bottom of 1 m depth (Boyd, 1995).

The increase in silt content and decrease in clay content at the start of the wet season (Fig. 3) were most probably due to the combined effects of surface run-off from the dykes and clay dispersion under the reduction of salinity (Sutherland et al., 2015). The annual sediment dredging did not exert significant effects on the particle size of bottom sediment, indicating that this practice removed only part of the accumulated sediment in the organic shrimp model.

Relationships between shrimp yields and physico-chemical characteristics

The organic shrimp model was no longer as productive as it was in the past as shown by the lower total shrimp yield of 355.4 $kg.ha^{-1}.year^{-1}$ compared to that harvested in 2012 (550–600 $kg.ha^{-1}.year^{-1}$) in the same area (Camimex, 2012). Because, there was no difference in the stocking densities, the most probable reason for yield reduction in the organic shrimp model could be due to the decline of pond quality. The wild shrimp yield contributed significantly (55 %) to the total yield. The positive correlations between the yield of wild shrimp and total yield and water depth (Table 2) were in accordance with previous findings in the mixed shrimp-mangrove systems in the Mekong delta (Johnston et al., 2000; Minh et al., 2001). The result implied that an increase in pond water depth might improve shrimp yield in the organic shrimp model.

The temperature was not a limiting factor to shrimp yield in this model as these were positively correlated (Table 2). Turbidity was positively correlated with the yield of wild shrimp, most probably due to the positive relationship between turbidity and content of organic matter content in shrimp pond water (Azim et al., 2005; Shaari et al., 2011). Inverse relationships between shrimp yields (cultured shrimp and total yield) and Fe^{2+} indicated negative impacts of iron to shrimp growth, in agreement with previous research (Poernomo, 1990; Boyd, 2008). The positive correlations between pH of pond sediment and shrimp yields (Table 2) suggested that shrimps grew well in neutral or near-neutral pond bottom, in accordance with previous research on fish production (Banerjea, 1967; Boyd and Pillai, 1984) or aquaculture production in general (Boyd, 1995).

Conclusion

The physico-chemical characteristics of pond water and sediment in the organic shrimp model were in general appropriate for shrimp growth. However, the pond quality of this model seemed to be declining. The most noticeable disadvantages for shrimp growth were the high iron contents, the shallow pond water, and to a lesser extent the excessive DO levels in the water column during the daytime. To improve the conditions for shrimp growth, appropriate changes should be made to the pond management. The most important measures are to increase the water depth to about 80–90 cm, avoid disturbing the pyritic-containing layer in the mangrove soils, and maintain a water level higher than the forest floor to reduce oxygen penetration into the mangrove soils. Further, liming is recommended for the treatment of acidity and possible pathogenic agents in pond sediment deposited on the dykes.

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